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SUITABILITY OF ETHERS AS AVIATION FUEL COMPONENTS

THE KNOCK-LIMITED PERFORMANCE OF SEVERAL

ETHERS BLENDED WITH AN-F-28 FUEL

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WASHINGTON

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INTRODUCTION

A general research project is being conducted by the NACA to determine the suitability of various ethers as components of aviation fuels. Investigations covering the physical and chemical properties of the various ethers and their antiknock effectiveness, as well as their methods of preparation and purification, are included.

The knock-limited performance of various ethers has been determined by many laboratories including those of the Army, the Navy, the engine manufacturers, and the various laboratories of the petroleum industry. Some of the ethers have shown considerable promise as high antiknock blending agents on nonsupercharged rating engines. Recent NACA tests of certain compounds such as methyl *tert*-butyl ether (see references 1, 2, and 3) on supercharged engines indicate that the knock-limited performance of the ethers should be thoroughly investigated.

The knock-limited performance of four aliphatic ethers and two aromatic ethers blended with AN-F-28 fuel were investigated on a supercharged CFR engine. The data obtained from these tests are presented herein and may be used to extend the evaluation of the antiknock effectiveness of the ethers as components of aviation fuel. These data were obtained at the Aircraft Engine Research Laboratory of the NACA, Cleveland, Ohio, on July 25, 1944.

APPARATUS AND TEST PROCEDURE

The experimental blends tested contained 90 percent AN-F-28, Amendment-2, fuel and 10 percent of the following four aliphatic ethers: methyl *tert*-butyl ether, ethyl *tert*-butyl ether, isopropyl *tert*-butyl ether, and di-*tert*-butyl ether; and the following two aromatic ethers: anisole (methyl phenyl ether) and phenetole (ethyl phenyl ether). The di-tert-butyl ether was prepared by Henry H. Chanan in the Fuel Synthesis Section of the Fuels and Lubricants Division. The other ethers were obtained from a commercial source and were distilled at the Cleveland laboratory. All blends were leaded to 4.6 milliliters of tetraethyl lead per gallon. Data covering the normal range of fuel-air ratios were obtained on 500 to 700 milliliters of the purified ether samples.

Because all tests were run on the same day, only one test of the base fuel was necessary. The tests were conducted on a high-speed supercharged CFR engine as described in reference 1; as in reference 1, the following engine conditions were maintained constant:

Engine speed, rpm	2500
Inlet-air temperature, °F	250
Coolant temperature, °F	250
Compression ratio	7.0
Spark advance, deg B.T.C.	30

RESULTS AND DISCUSSION

Figure 1 presents the knock-limited performance data for the six ethers and the base fuel. The aliphatic ethers gave improved knock-limited performances over the normal fuel-air-ratio range, whereas the aromatic ethers did not show any improvement in the fuel-air-ratio range from 0.067 to 0.082. All the ether blends allowed higher knock-limited performance than AN-F-28 fuel in the extremely lean-mixture and rich-mixture regions. The performance data on methyl tert-butyl ether was limited because of a lack of material but enough data from reference 1 were used to extrapolate the curve. The agreement between the rich-mixture performances of the two sets of data was satisfactory.

The experimentally determined boiling points, freezing points, and the net heats of combustion of the blend components are listed in table I. The effect of the various ether blends on the knock-limited performance is presented in table II as well as in figure 2. In the consideration of these summaries, reference should be made to figure 1, because the aromatic ethers show a fuel-air-ratio shift of the minimum knock point. It is believed that this shift partly accounts for the slight depreciation in knock-limited power exhibited by anisole and phenetole between fuel-air ratios of 0.067 and 0.082.

Although methyl tert-butyl ether gave the best knock-limited rich mixture response, isopropyl tert-butyl ether and di-tert-butyl ether gave better results at lean mixtures. Isopropyl *tert*-butyl ether and di-*tert*-butyl ether also have higher net heats of combustion than methyl *tert*-butyl ether. (See table I.)

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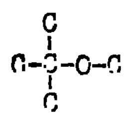
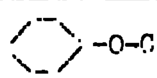
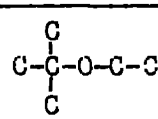
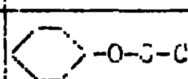
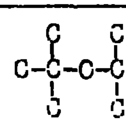
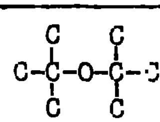
REFERENCES

1. Bellman, Donald R.: The Knock-Limited Performance of Several Miscellaneous Fuels Blended with a Base Fuel. NACA ACR No. E4G08, 1944.

2. Barnett, Henry C. and Slough, James W.: Supercharged-Engine Knock Tests of Methyl *tert*-Butyl Ether. NACA ACR No. E4H10, 1944.

3. Barnett, Henry C., Meyer, Carl L., and Jones, Anthony W.: Engine and Inspection Tests of Methyl *tert*-Butyl Ether as a Component of Aviation Fuel. NACA ACR No. E4H03, 1944.

TABLE I - SUMMARY OF PHYSICAL ETHER DATA

Test blend (10 percent ether plus 90 percent AN-F-28 fuel)	Molecular structure	Freezing point (°F)	Boiling point (°F)	Experimental net heat of combustion (Btu/lb)	Calculated[1] net heat of combustion of blend (Btu/lb)
AN-F-28 fuel		------	------	18,900	------------
Methyl tert-butyl ether		-164	131	15,200	18,530
Anisole (methyl phenyl ether)		-35	306	14,400	18,450
Ethyl tert-butyl ether		-137	160	15,500	18,560
Phenetole (ethyl phenyl ether)		-21	332	14,700	18,430
Isopropyl tert-butyl ether		-128	189	15,900	18,600
Di-tert-butyl ether		-78	214	16,200	18,630

[1]Calculated net heat of combustion of blend of 10 percent ether plus 90 percent AN-F-28 fuel.

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TABLE II - SUMMARY OF KNOCK-LIMITED PERFORMANCE DATA

Test blend (10 percent ether plus 90 percent AN-F-28 fuel)	Relative power[a]					
	Fuel-air ratio			Percentage of stoichiometric mixture[b]		
	0.062	0.080	0.110	92	118.7	163.2
AN-F-28	1.00	1.00	1.00	1.00	1.00	1.00
Methyl *tert*-butyl ether	1.10	1.11	1.21	1.11	1.14	1.22
Anisole (methyl phenyl ether)	1.05	1.00	1.08	1.04	1.05	1.09
Ethyl *tert*-butyl ether	1.05	1.11	1.07	1.05	1.13	1.07
Phenetole (ethyl phenyl ether)	1.12	0.99	1.13	1.10	1.05	1.13
Isopropyl *tert*-butyl ether	1.15	1.11	1.08	1.15	1.12	1.08
Di-*tert*-butyl ether	1.17	1.07	1.06	1.16	1.09	1.06

[a]Relative power = $\frac{\text{imep (10 percent ether plus 90 percent AN-F-28 fuel)}}{\text{imep (AN-F-28 fuel)}}$

[b]Percentages of stoichiometric mixtures corresponding to fuel-air ratios of 0.062, 0.080, and 0.110, respectively, for AN-F-28 aviation fuel.

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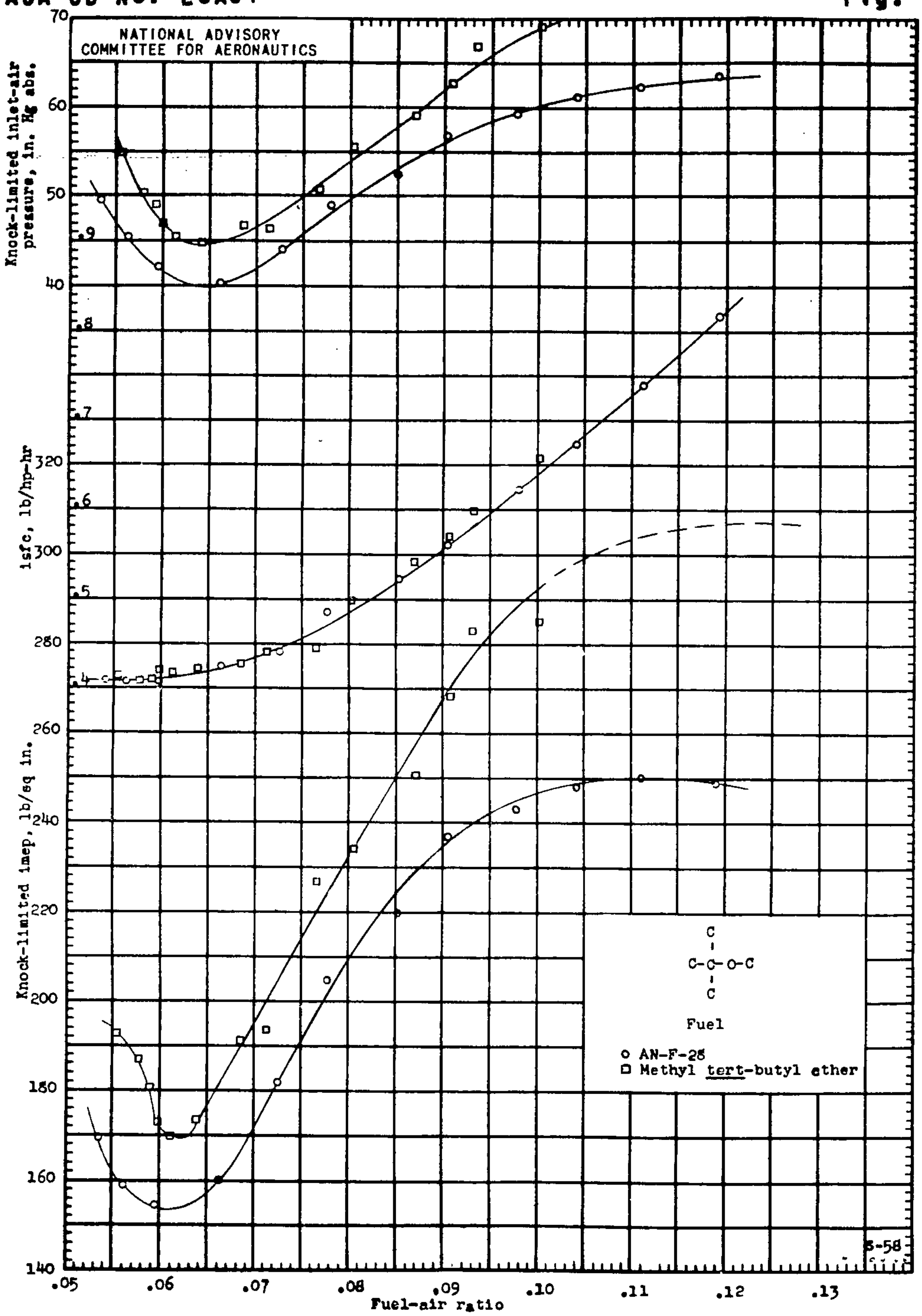
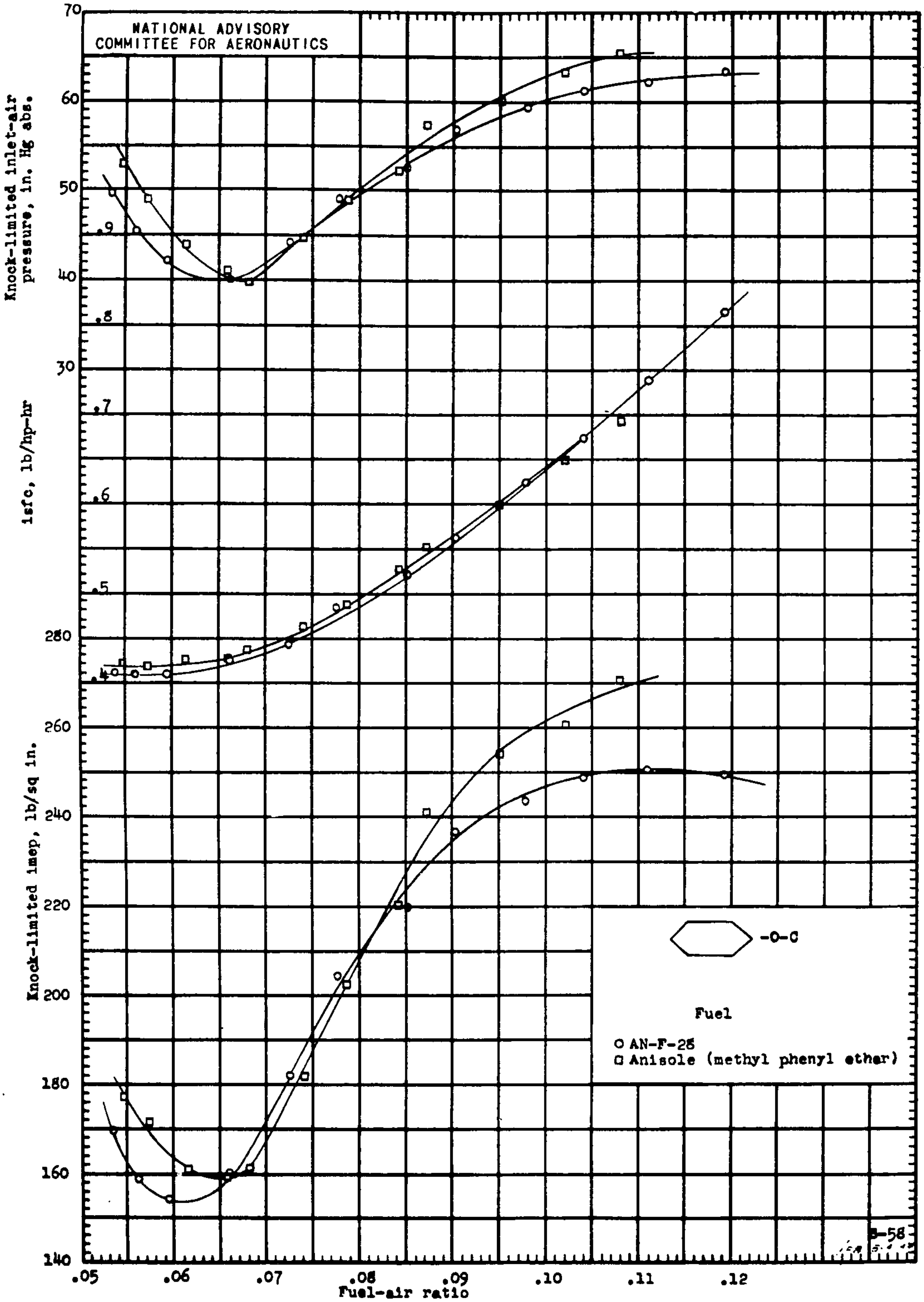
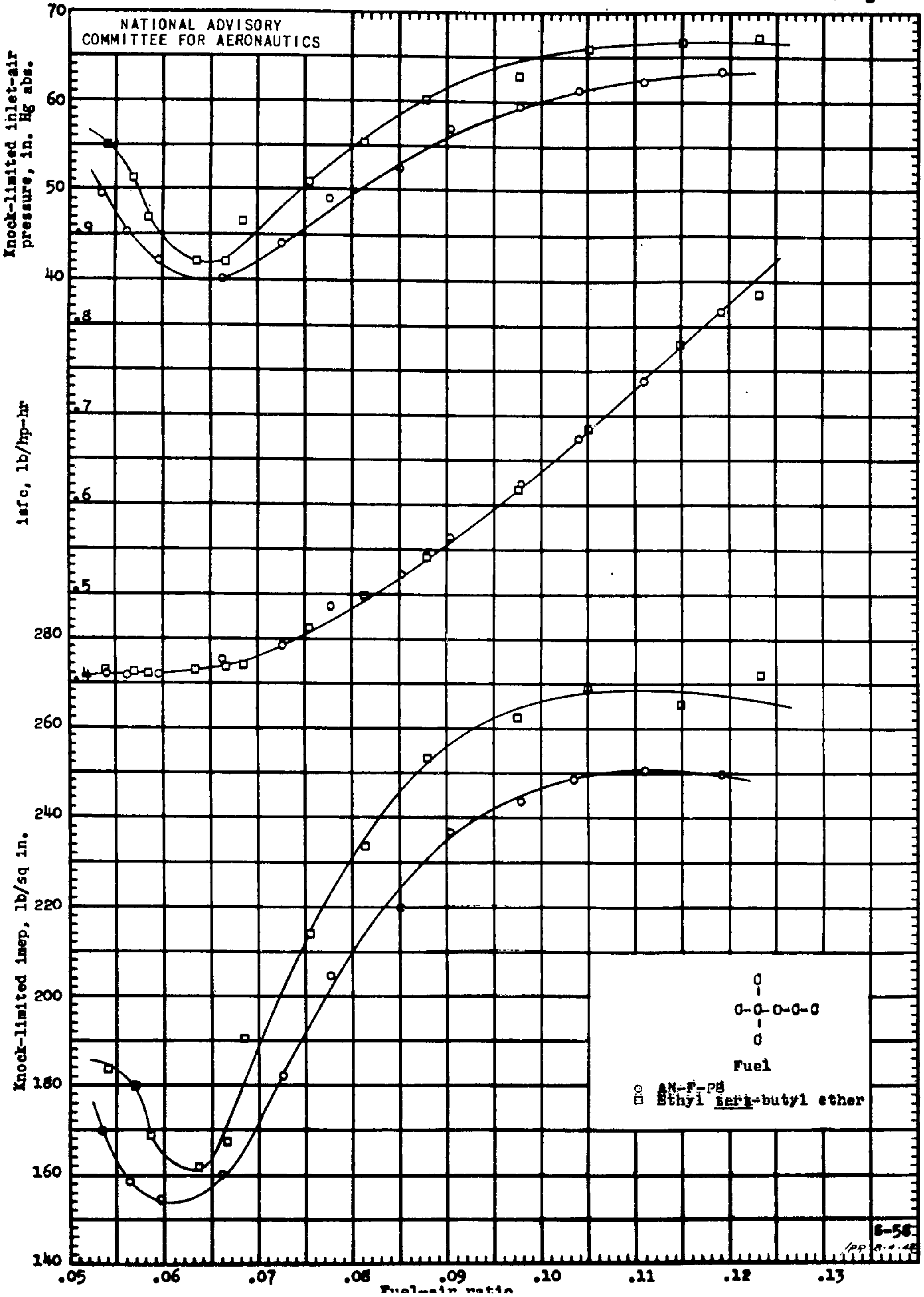


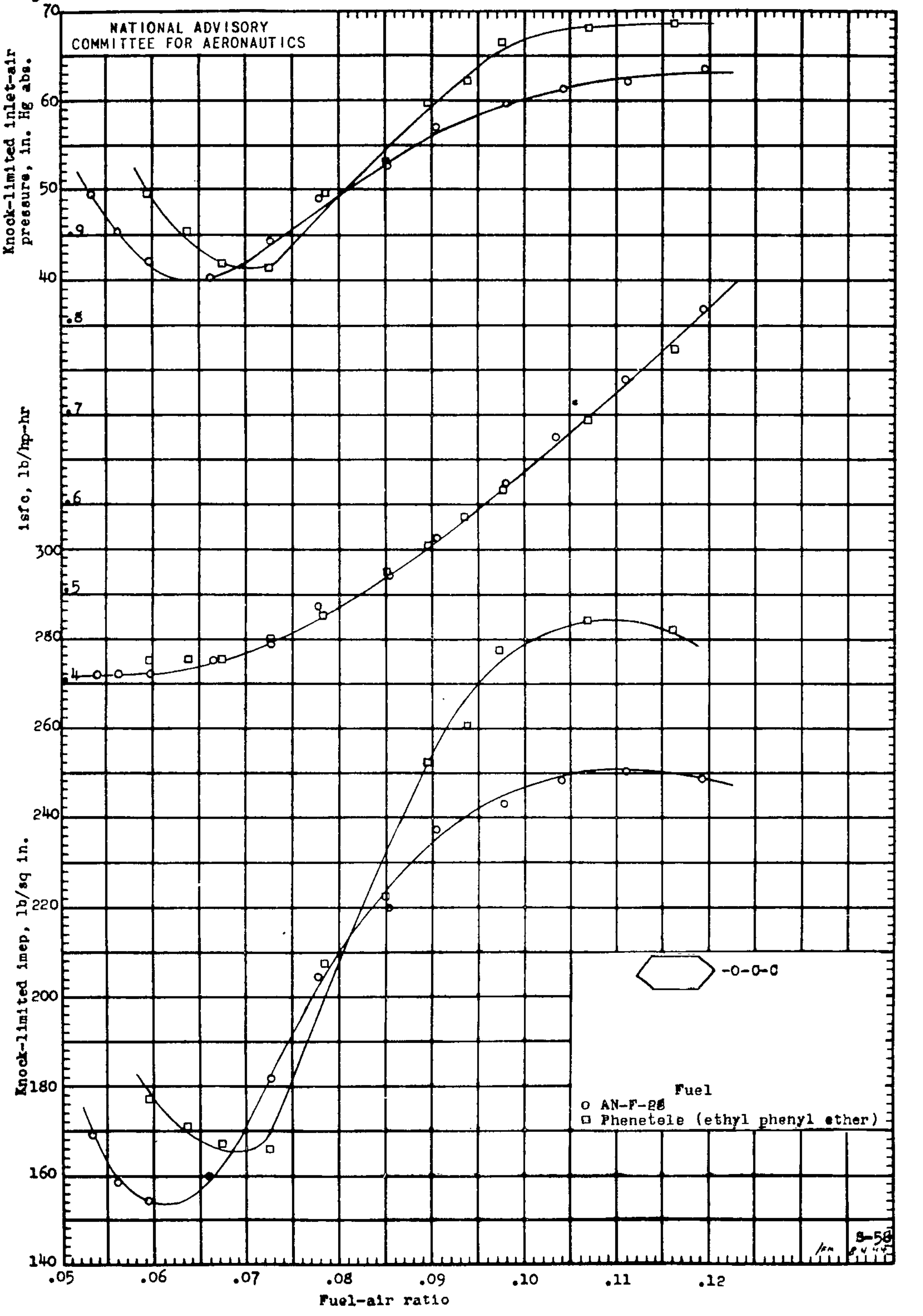
(a) Methyl tert-butyl ether.
Figure 1. - The knock-limited performance of blends of 90 percent AN-F-28 fuel and 10 percent of several ethers. Supercharged CFR engine; compression ratio, 7.0; coolant temperature, 250° F; inlet-air temperature, 250° F; spark advance, 30° B.T.C.; engine speed 2500 rpm.



(b) Anisole (methyl phenyl ether).
Figure 1. - Continued. The knock-limited performance of blends of 90 percent AN-F-28 fuel and 10 percent of several ethers. Supercharged CFR engine; compression ratio, 7.0; coolant temperature 250° F; inlet-air temperature 250° F; spark advance 30° B.T.C.; engine speed 2500 rpm.

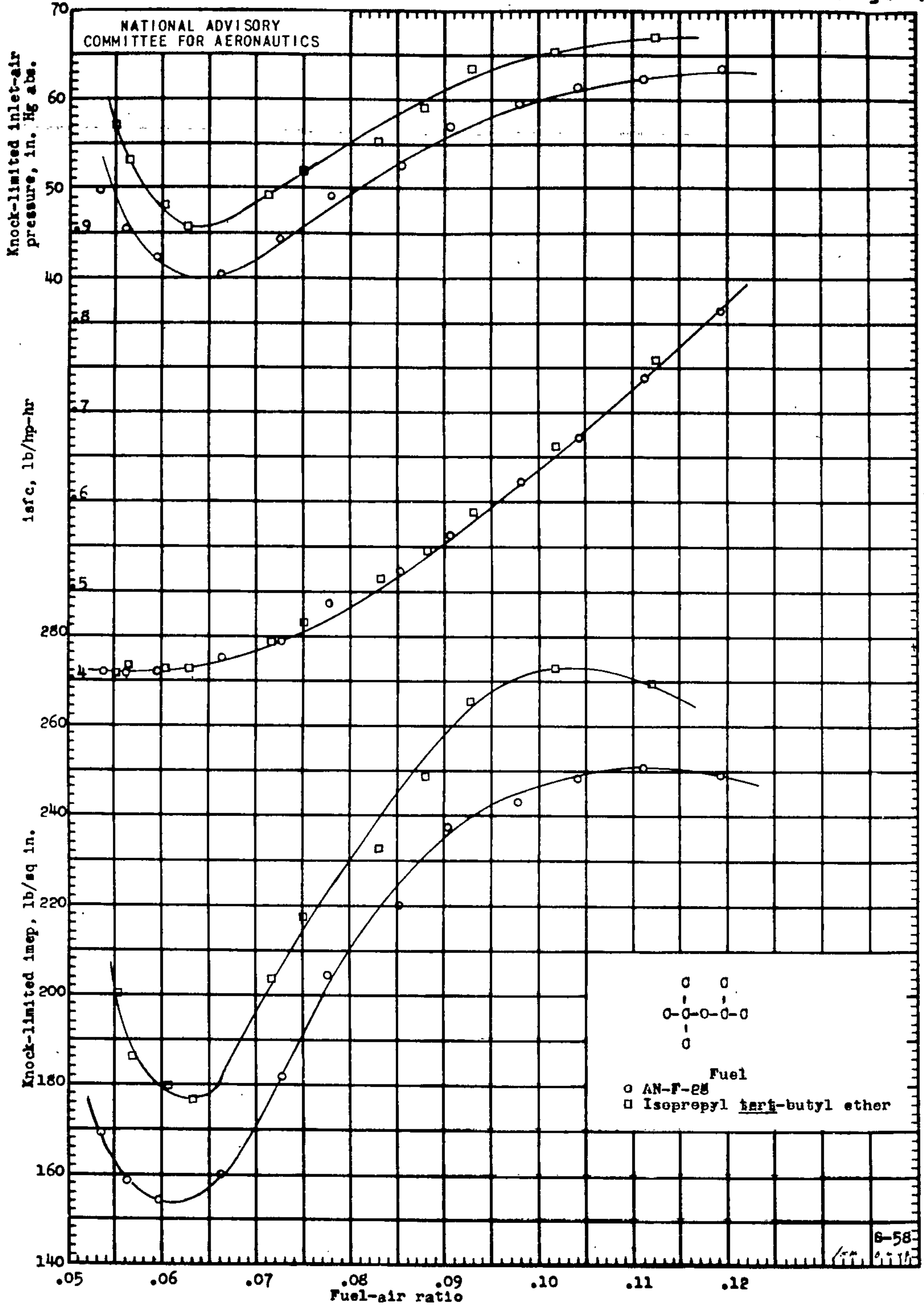


(c) Ethyl tert-butyl ether.
Figure 1. - Continued. The knock-limited performance of blends of 90 percent AN-F-28 fuel and 10 percent of several ethers. Supercharged CFR engine; compression ratio, 7.0; coolant temperature 250° F; inlet-air temperature 250° F; spark advance, 30° B.T.C.; engine speed 2500 rpm.



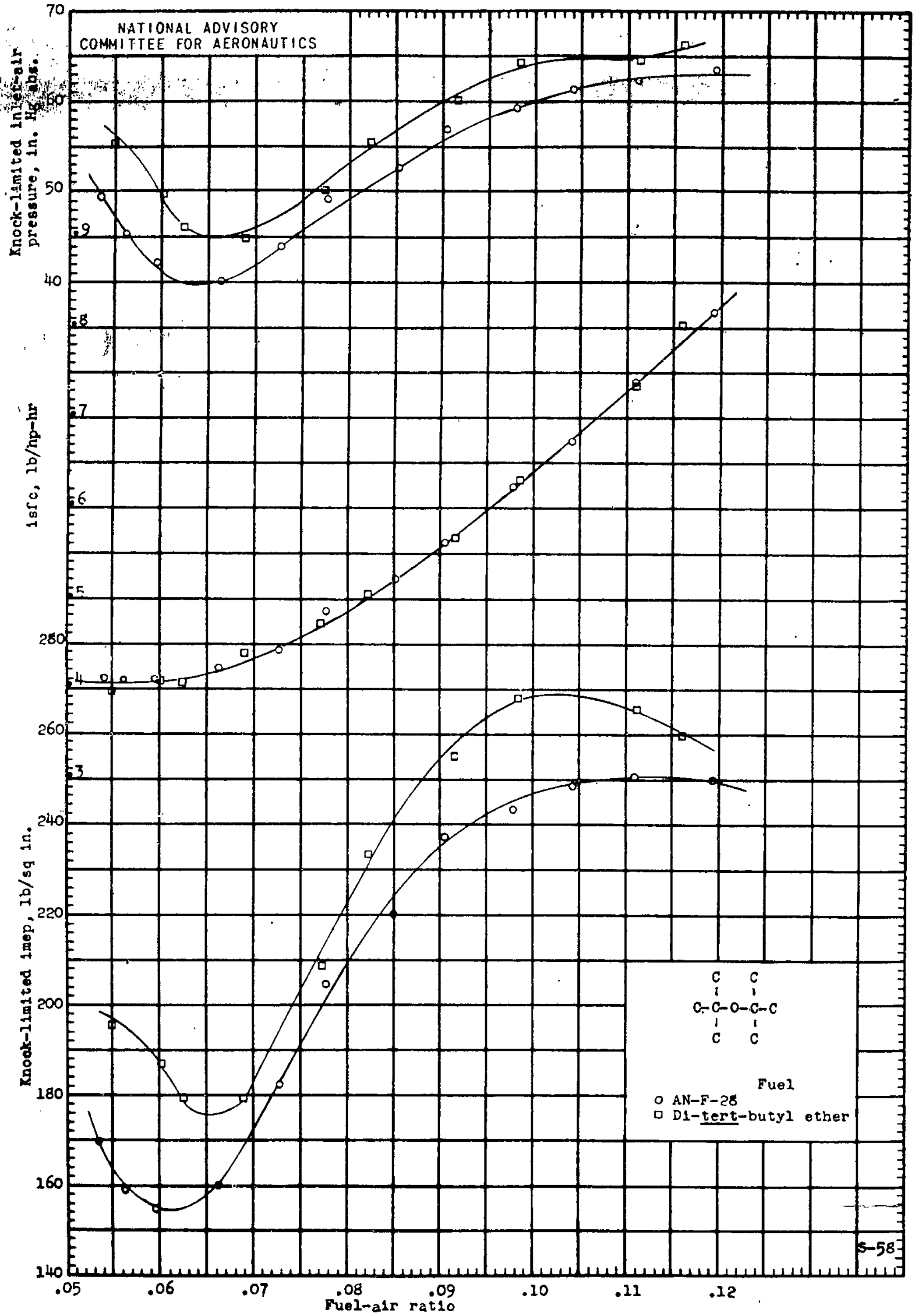
(d) Phenetole (ethyl phenyl ether).

Figure 1. - Continued. The knock-limited performance of blends of 90 percent AN-F-28 fuel and 10 percent of several ethers. Supercharged CFR engine; compression ratio, 7.0; coolant temperature 250° F; inlet-air temperature 250° F; spark advance 30° B.T.C.; engine speed 2500 rpm.



(e) Isopropyl *tert*-butyl ether.

Figure 1. - Continued. The knock-limited performance of blends of 90 percent AN-F-28 fuel and 10 percent of several ethers. Supercharged CFR engine; compression ratio, 7.0; coolant temperature 250° F; inlet-air temperature 250° F; spark advance 30° B.T.C.; engine speed 2500 rpm.



(f) Di-tert-butyl ether.
Figure 1. - Concluded. The knock-limited performance of blends of 90 percent AN-F-28 fuel and 10 percent of several ethers. Supercharged CFR engine; compression ratio, 7.0; coolant temperature 250° F; inlet-air temperature 250° F; spark advance 30° B.T.C.; engine speed 2500 rpm.

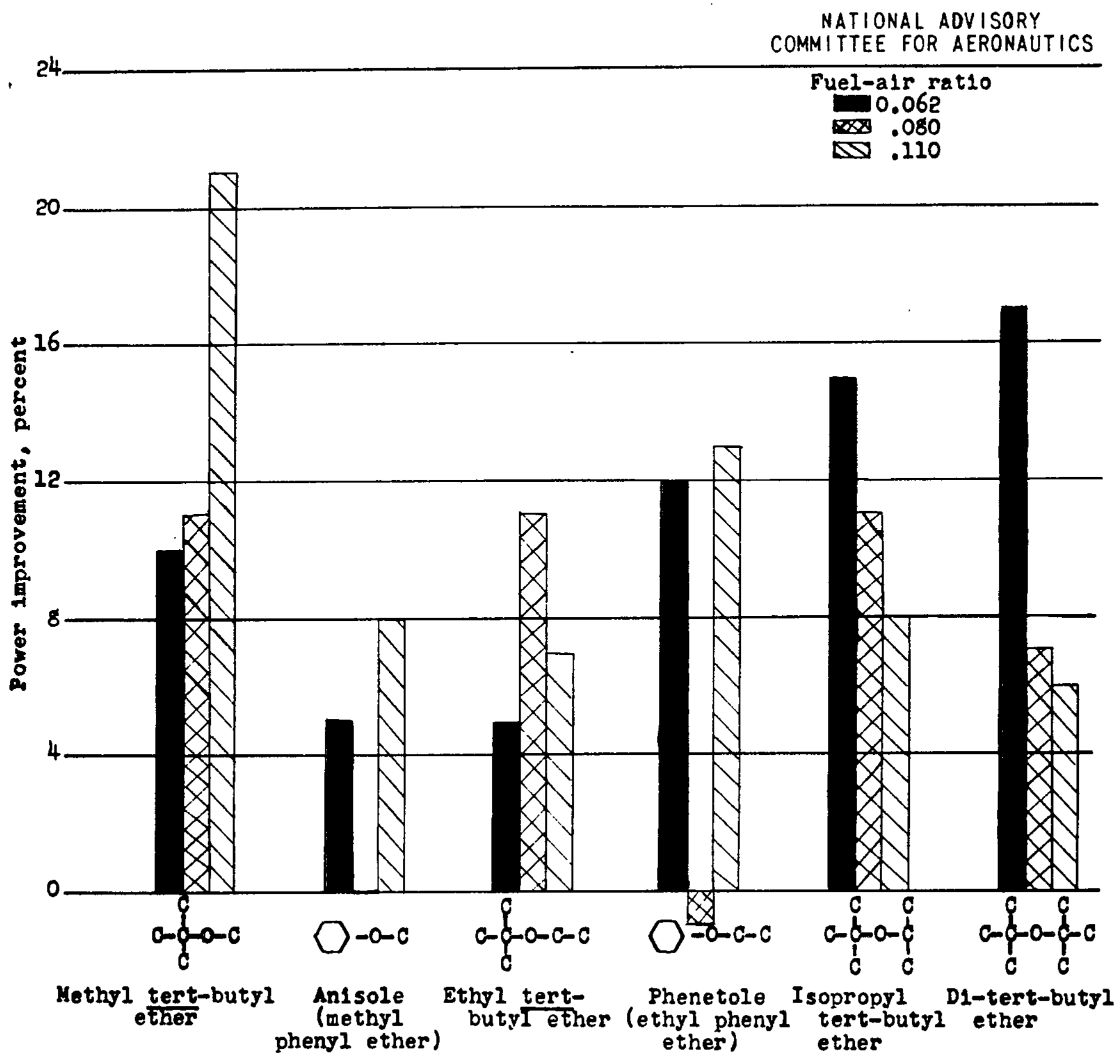


Figure 2. - Comparison of the performance of blends containing 90 percent AN-F-28 fuel and 10 percent of various ethers.